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RESEARCH MEMORANDUM

RECENT DESIGN STUDIES DIRECTED TOWARD ELIMINATION OF PITCH-UP

By Joseph Weil and W. H. Gray

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November 18, 1953 [redacted]

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INTRODUCTORY REMARKS

The function of the present paper is to present the results of recent design studies of complete configurations expressly directed toward elimination of high-speed pitch-up. Tail-off results for some of the configurations presented herein can be found in reference 1.

Before proceeding with the discussion it should be stated that methods are available from which arbitrary nonlinear aerodynamic characteristics can readily be converted into calculated time histories of representative flight maneuvers. (See ref. 2.) Such calculations obviously do not have the value of flight tests but nevertheless are very useful in serving as a guide in interpreting wind-tunnel data and in studying the importance of the various factors affecting the overall problem.

The application of the calculation method to evaluate the effectiveness of corrective control for a given pitching-moment shape is illustrated in figure 1.

The particular pitching-moment curve used had a region of neutral stability. A ramp stabilizer input was applied at 1 degree per second. It was assumed the pilot desired to arrest the motion at $\alpha = 8^{\circ}$; however, because of reaction-time delay and control lag it was further assumed that there was a 0.5-second delay before either the control motion was stopped or the 4-degrees-per-second corrective control applied.

An important factor in determining the controllability of an overshoot is a term proportional to the ratio of the aerodynamic moment to the airplane moment of inertia. For a value of this dynamic response factor of 16 (representative of an airplane primarily loaded along the fuselage and flying at altitude at transonic speeds), it is evident that corrective control was instrumental in appreciably reducing the overshoot although the peak angle reached was still about 5° greater than would have been attained with a linear pitching-moment curve and therefore undesirable.

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For a dynamic response factor of 64 (representative of an airplane primarily loaded along the wings), the motion builds up so rapidly that corrective control is completely ineffective in reducing the overshoot.

It should be noted that the interpretation of some of the results to be presented in this paper are based on calculations such as these where flight experience with configurations having similar characteristics was not available.

The problem of tail location (from the stability standpoint) is one of matching the stability contribution of the tail to the wing-fuselage characteristics. The manner in which the choice of tail location might be affected by three different types of simplified wing-fuselage pitching-moment curves is shown in figure 2.

With a tail-off curve characterized by a stable break at moderate angle of attack, location of the tail so that it approaches the wing wake with reduced tail contribution to stability in the moderate α range will tend to linearize the stability characteristics of the complete configuration. For a wing-fuselage curve with a mild destabilizing break, the use of a somewhat lower tail with the tail contribution to stability shown might be desired. When the wing-fuselage curve indicates a large unstable change at moderate angle of attack, the only possibility of securing an acceptable complete configuration lies in the use of a tail low enough so that its emergence from the wing wake and resulting increased stability contribution will overcome the tail-off instability.

SCOPE

The scope of the complete configurations to be discussed in this presentation is shown in figure 3. The configurations studied were conceived as having all-movable tails and the tail lengths varied from 1.2 to 1.4 wing semispans. Stability information showing effects of changes in tail height is presented for these configurations in subsequent figures. The Reynolds numbers of the data were generally of the order of from 3×10^6 to 4×10^6. Most of the investigations were made at high subsonic Mach numbers, the range in which the most serious pitch-up is usually encountered.

DISCUSSION

The effect of varying tail height on the pitching-moment characteristics of an aspect-ratio-3 wing having an unswept 50-percent-chord line is shown in figure 4. The wing had a taper ratio of 0.2 and a 4-percent-thick airfoil. Data are presented at a Mach number of 0.80 and 0.90 for

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tail heights of 0, 32, and 64 percent of the wing semispan above the wing chord plane extended. A reference center-of-gravity location has been chosen for each tail height such that an initial slope $\frac{\partial C_m}{\partial C_L} = -0.12$ was obtained at $M = 0.80$. (See table I.) The lift curve is shown for reference purposes.

It is seen that, at $M = 0.80$, some overshoot would be experienced at high C_L for either of the two higher tails. Although the highest tail shows an abrupt instability, it is not thought that this instability would seriously limit the usefulness of the airplane because the pitch-up tendency is preceded by a pronounced stable break in the moment curve which would serve as a warning to the pilot and occurs at an angle of attack considerably above the severe break in the lift curve and therefore probably well into the heavy buffet region. No pitch-up problem is indicated for the lift range obtained at $M = 0.90$. Somewhat similar results were obtained from an investigation of an unswept wing of aspect ratio 4 and taper ratio 0.6. (See fig. 5.)

The effects of reducing the aspect ratio of a moderately swept wing from 4 to 3 are presented in figure 6. Inasmuch as the lower-aspect-ratio wing was formed by cutting off the tips of the aspect-ratio-4 configuration, the taper ratio increased from 0.60 to 0.68. Data are presented for a Mach number of 0.90 for a tail located approximately 15 percent semispan above and below the wing chord plane extended.

For the tail located above the fuselage, a pitch-up tendency is shown for either aspect ratio wing coincident with an abrupt break in the lift curve. For the aspect-ratio-4 wing, the severity of the C_m break would indicate a fairly severe pitch-up. Reducing the aspect ratio to 3 delayed the onset of pitch-up by about $0.1C_L$ and the importance of the much milder pitch-up tendency indicated is questionable in view of the probable presence of appreciable buffet.

With the tail located below the fuselage, no pitch-up tendency is shown for either aspect ratio.

Figure 7 illustrates the effect of taper ratio on the stability characteristics of configurations having an aspect ratio of 3 and quarter-chord sweep of 30°. Data are presented at Mach numbers of 0.92 and 1.06 for a tail located on the chord plane extended and 64 percent of the wing semispan above the chord plane extended.

At $M = 0.92$, regardless of tail height and taper ratio, a jog is present in the moment curve at moderate lift coefficient. The destabilizing tendencies, however, occur at a lift coefficient about 0.2 higher for the wing having 0.5 taper and would appear to be somewhat less severe.

For either taper ratio, an abrupt instability is present at extremely high α as the high tail approaches the wake. At a Mach number of 1.06, no pitch-up problem is indicated in the lift range obtained.

The effect of tail height on the stability characteristics of a 45° delta wing with tips clipped to form a wing with an aspect ratio of 3 are given in figure 8. The taper ratio was 0.14 and the quarter-chord sweep, 36.8°. Of the three tail positions investigated, the middle tail was clearly the worst. For the high tail, the lift coefficient at which a pronounced instability exists at $M = 0.80$ was delayed to an angle of attack of 18° or well beyond the abrupt break in the lift curve. The chord-plane tail had fairly acceptable characteristics at both Mach numbers. Thus for this arrangement, it is obvious that a low tail or a very high tail represents the best choice of tail location from the pitch-up standpoint.

The effect of Mach number on the stability characteristics of a configuration having a 47° swept wing of aspect ratio 3.5 is shown in figure 9 for tail heights of 6 and 56 percent of the wing semispan above the wing chord plane. Figure 9 shows that, although the instability was less pronounced for the lower tail, neither configuration had acceptable pitch-up characteristics. Furthermore, the results show that the onset of pitch-up is delayed to a progressively higher lift coefficient as the Mach number is increased from 0.90 to 1.04. For the lower tail it is also evident that the severity of the pitch-up tendency is considerably reduced at the highest Mach number.

The effect of tail height on the stability characteristics of a 45° swept wing of aspect ratio 4 at a Mach number of 0.90 is shown in figure 10. The wing-fuselage characteristics are such that, even when the tail is placed $0.14b/2$ below the fuselage, undesirable pitching-moment characteristics are retained.

The effect of a leading-edge modification on the stability characteristics of the 45° wing at $M = 0.90$ is presented in figure 11. The leading-edge modification used consisted of a 10-percent chord-extension from 65 percent semispan to the wing tip and a full-span 20-percent-chord nose flap. The combination was drooped 6° streamwise and hinged about the 20-percent chord line. Such an arrangement has been shown to have favorable performance characteristics at high subsonic speeds. See reference 3.

For a tail location above the fuselage, the use of the modified wing delayed the onset of pitch-up by about $0.1C_L$. The severity of the pitch-up, however, would not appear to be altered. When the tail is placed below the fuselage it would appear that the use of the modification would result in fairly acceptable pitching-moment characteristics. See reference 4.

The importance of localized inboard plan-form modifications on the tail contribution to stability at $M = 0.90$ is illustrated in figure 12. The inboard modifications were added to the configuration having nose droop and chord-extensions. Pitching-moment and tail contribution to the stability $\left(C_{m_\alpha}\right)_t$ are plotted against angle of attack.

On the left-hand side of figure 12 is shown the effect of adding a trailing-edge extension inboard of the 40-percent-semispan station. The tail height was 0.26b/2 above the chord plane extended. It is evident that the addition of the extension increased the severity of the instability. The reason for this increase is traceable to the highly destabilizing effect of the trailing-edge extension on the tail contribution to the stability.

On the right-hand side of figure 12 is shown the effect of a root indentation extending inboard of the 30-percent-semispan station intersecting the fuselage at about the 30-percent-chord line. A tail height of 14-percent semispan above the chord plane was used for this study. A significant improvement in the stability characteristics is shown for the configuration with root indentations. The reason for this improvement is traceable to the stabilizing effect of the indentation on the tail contribution to stability.

The effects of more extreme plan-form modifications are summarized in figures 13 and 14. Data are presented for the basic 45° wing of aspect ratio 4, for a cranked wing with inboard sections swept 45° and outboard 40-percent-semispan sections unswept, and for an M-plan-form wing with inboard 40-percent-semispan sections swept forward 45° and outboard sections swept back 45°. Results are presented at Mach numbers of 0.80 and 0.90 and for tail heights of 0, 27, and 55 percent above the chord plane.

For the basic swept wing it has been previously shown that, because of the nature of the tail-off characteristics, no tail location produced acceptable stability characteristics.

From the results with the cranked wing it would appear that somewhat better characteristics were obtained for the low tail than for the corresponding swept-wing configuration. Although the high tail investigated would not be acceptable, there was a definite improvement over the results obtained with the swept wing and the use of an extremely high tail should not be ruled out. The mid-tail showed essentially no improvement and had by far the worst stability characteristics.

For the M-plan-form wing, no pitch-up is indicated for the chord-plane tail. For the high tail, the lift coefficient at which pitch-up is indicated is almost twice that for the swept wing at $M = 0.80$ and substantial gains over the swept wing are also shown at $M = 0.90$. A somewhat

higher tail location than that tested would, however, in this instance also be desirable. The characteristics of the mid-tail were considerably improved over the comparable swept-wing configuration but this tail location still appears the least desirable of the three locations investigated.

SUMMARY OF RESULTS

Figure 15 is used as an aid in summarizing the results and is essentially a high-speed counterpart of the Shortal-Maggin boundary for wing and wing-fuselage configurations (see ref. 5). The configurations have been evaluated in the Mach number range from 0.80 to 0.95, the speed range for which the most serious pitch-up can be expected for many configurations. The points plotted are for simple wing and wing-fuselage combinations having thicknesses from 3 to 6 percent streamwise. The open symbols define the combinations of aspect ratio and sweep that produce pitching-moment characteristics that would not of themselves constitute a pitch-up problem, whereas the solid symbols represent configurations having unacceptable tail-off pitching-moment characteristics. The half-filled symbols define configurations which, when combined with a fairly constant tail contribution to stability, would produce marginal pitch-up characteristics. The boundary region represents wings having more or less marginal characteristics.

For configurations having wings falling on the left side of the boundary, caution must be exercised to avoid placing the tail in a region of unfavorable flow characteristics. For the aspect-ratio-3, essentially unswept wing investigated, it was not considered that a serious pitch-up problem existed; however, for a range of high tail positions a pitch-up tendency would be encountered at extremely high angles of attack.

For configurations falling in the boundary area, the tail must be located so as not to aggravate but, if possible, to improve the wing characteristics. For these wings it was usually found that a moderately high tail location produced the most serious pitch-up tendency. A very high or moderately low tail would give more marginal results and only a very low tail produced good characteristics.

For wings falling above the boundary, the tail must overcome the undesirable wing characteristics. For the rather thoroughly investigated 45° swept aspect-ratio-4 wing, undesirable pitch-up would probably be present at all rational tail positions. The use of wing "fixes" combined with a very low tail produced an acceptable configuration for this wing. The use of localized plan-form modifications and composite plan forms offers the possibility of greater latitude in tail location for wings of this type and warrants further study.

Finally, it should be remembered that only the constant-speed pitch-up has been treated in this paper. Large and abrupt changes in pitching moment with Mach number, however, can also produce severe pitch-up and should be avoided if possible.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 11, 1953.

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TABLE I.- REFERENCE CENTER-OF-GRAVITY LOCATIONS

$$\left[\frac{\partial C_m}{\partial C_L} = -0.12 \text{ at } M = 0.8;\ \text{low } C_L\right]$$

Figure	Aspect ratio	$\Lambda_{c/4}$, deg	λ	Remarks	$h_t/b/2$	Reference center of gravity
4	3	12.6	0.20		0	$0.04\bar{c}$
4	3	12.6	.20		0.32	$.13\bar{c}$
4	3	12.6	.20		.64	$.21\bar{c}$
5	4	0	.60		0	$.14\bar{c}$
5	4	0	.60		.27	$.16\bar{c}$
5	4	0	.60		.55	$.25\bar{c}$
6	4	32.6	.60		-.14	$.24\bar{c}$
6	4	32.6	.60		.14	$.23\bar{c}$
6	3	32.6	.68		-.17	$.25\bar{c}$
6	3	32.6	.68		.17	$.22\bar{c}$
7	3	30	.20		0	$.17\bar{c}$
7	3	30	.20		.64	$.36\bar{c}$
7	3	30	.50		0	$.13\bar{c}$
7	3	30	.50		.64	$.32\bar{c}$
8	3	36.8	.14		0	$.19\bar{c}$
8	3	36.8	.14		.32	$.28\bar{c}$
8	3	36.8	.14		.64	$.32\bar{c}$
9	3.5	47	.20		.06	$.35\bar{c}$
9	3.5	47	.20		.56	$.40\bar{c}$
10	4	45	.30		-.14	$.36\bar{c}$
10	4	45	.30		.14	$.34\bar{c}$
10	4	45	.30		.26	$.37\bar{c}$
11	4	45	.30	Chord extension and nose droop	-.14	$.36\bar{c}$
11	4	45	.30	Chord extension and nose droop	.14	$.30\bar{c}$
12	4	45	.30	Inboard modification	.14	$.36\bar{c}$
12	4	45	.30	Inboard modification	.26	$.33\bar{c}$
13	4	45	.30	Fuselage differs slightly from that used in figures 10-12	0	$.29\bar{c}$
13	4	45	.30		.27	$.34\bar{c}$
13	4	45	.30		.55	$.40\bar{c}$
13	4	45° inboard; 0° outboard	.30	Cranked plan form	0	$.11\bar{c}$
13	4	45° inboard; 0° outboard	.30	Cranked plan form	.27	$.18\bar{c}$
13	4	45° inboard; 0° outboard	.30	Cranked plan form	.55	$.24\bar{c}$
14	4	-45° inboard; 45° outboard	.30	M plan form	0	$.04\bar{c}$
14	4	-45° inboard; 45° outboard	.30	M plan form	.27	$.11\bar{c}$
14	4	-45° inboard; 45° outboard	.30	M plan form	.55	$.17\bar{c}$

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EFFECT OF CORRECTIVE CONTROL IN TIME HISTORY OF PULL-UP

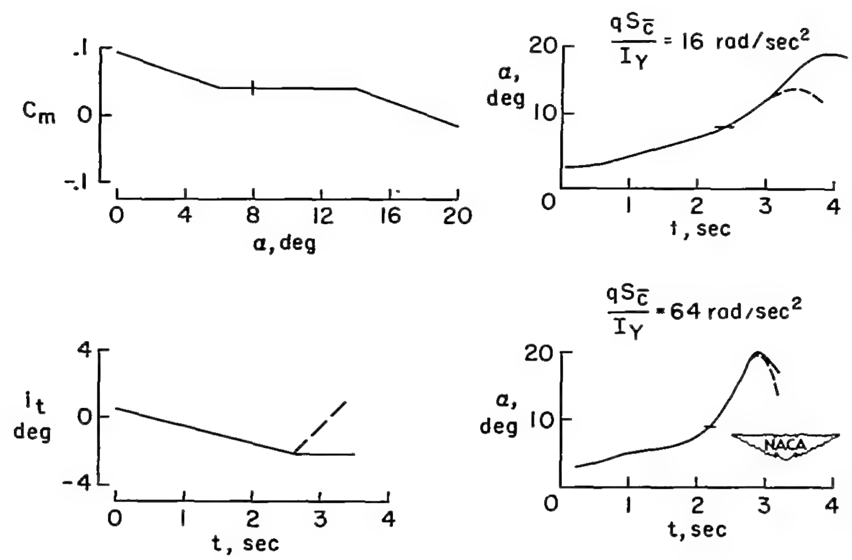

Figure 1

ILLUSTRATION OF PROBLEM

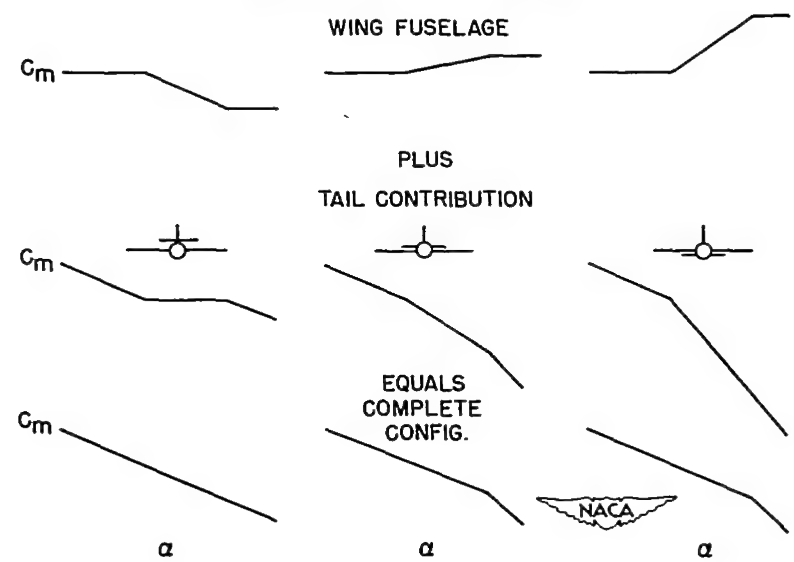

Figure 2

SCOPE

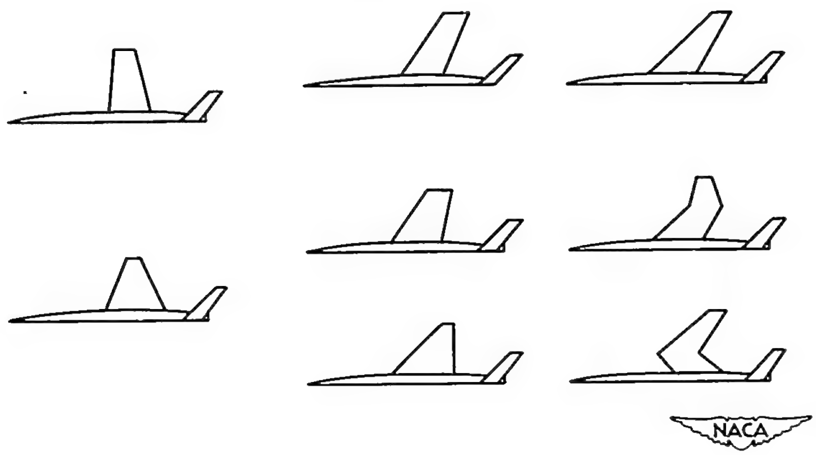

Figure 3

EFFECT OF TAIL HEIGHT

$\Lambda_{c/2} = 0°$; $A = 3$; $\lambda = 0.2$; NACA 65A004

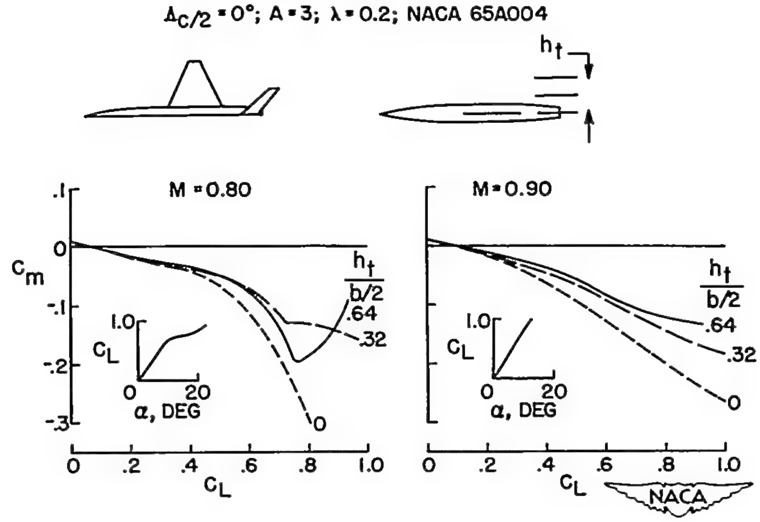

Figure 4

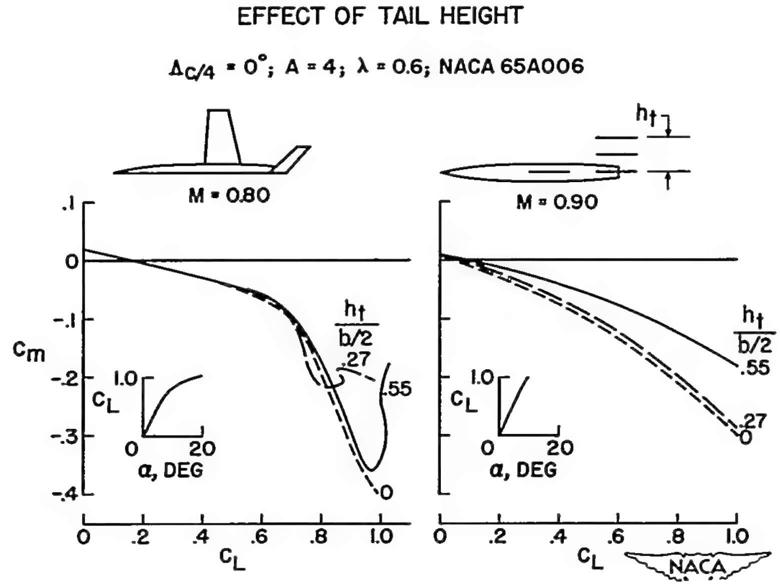

Figure 5

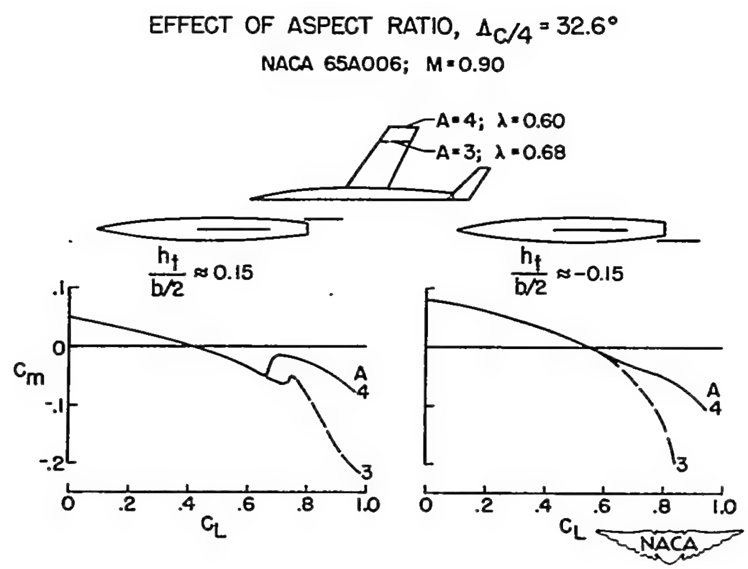

Figure 6

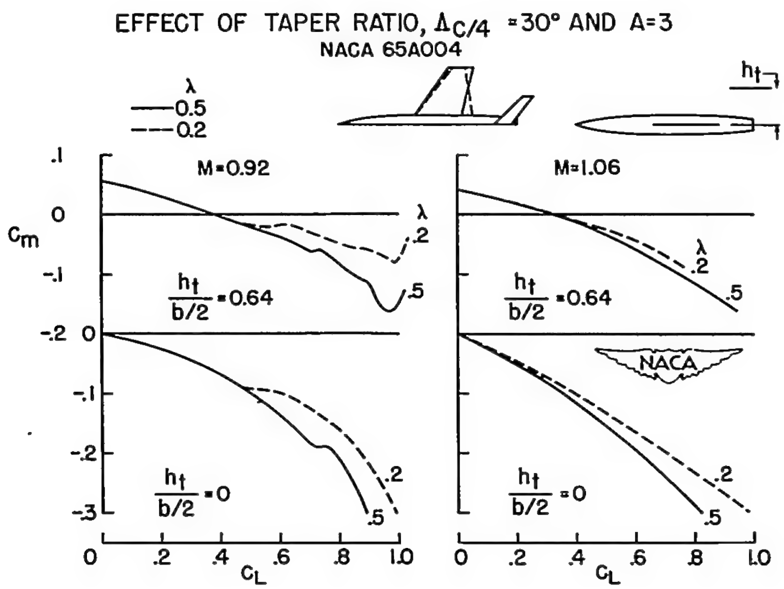

Figure 7

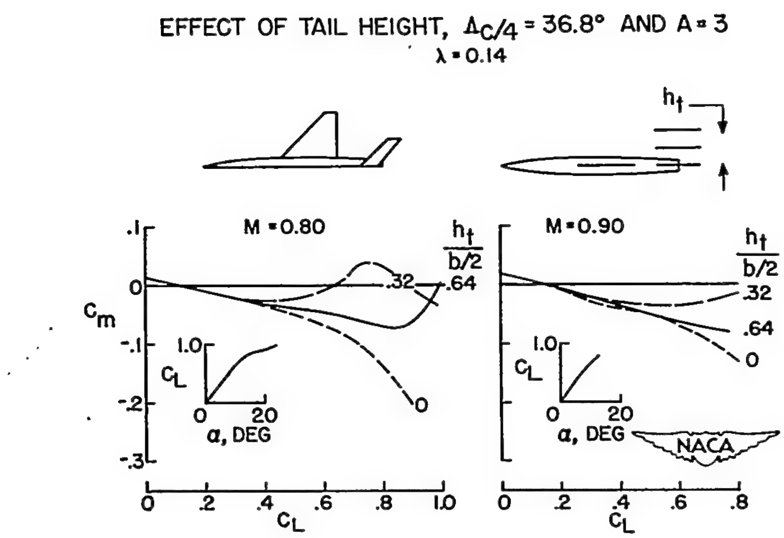

Figure 8

EFFECT OF MACH NUMBER, $\Lambda_{c/4} = 47°$ AND $A = 3.5$

$\lambda = 0.2$; $t/c = 0.055$

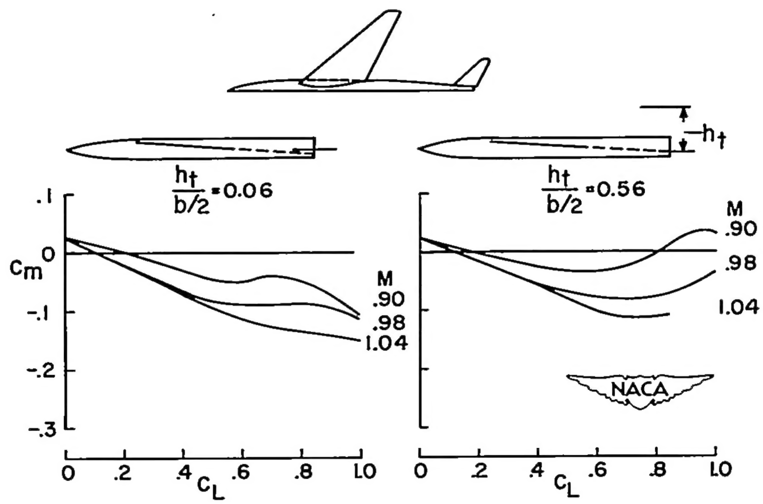

Figure 9

EFFECT OF TAIL HEIGHT, $\Lambda_{c/4} = 45°$ AND $A = 4$

$\lambda = 0.3$; NACA 65A006

$M = 0.90$

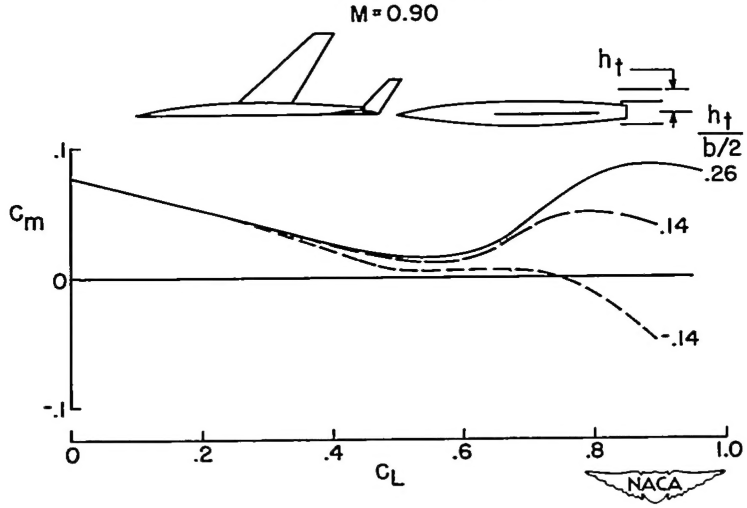

Figure 10

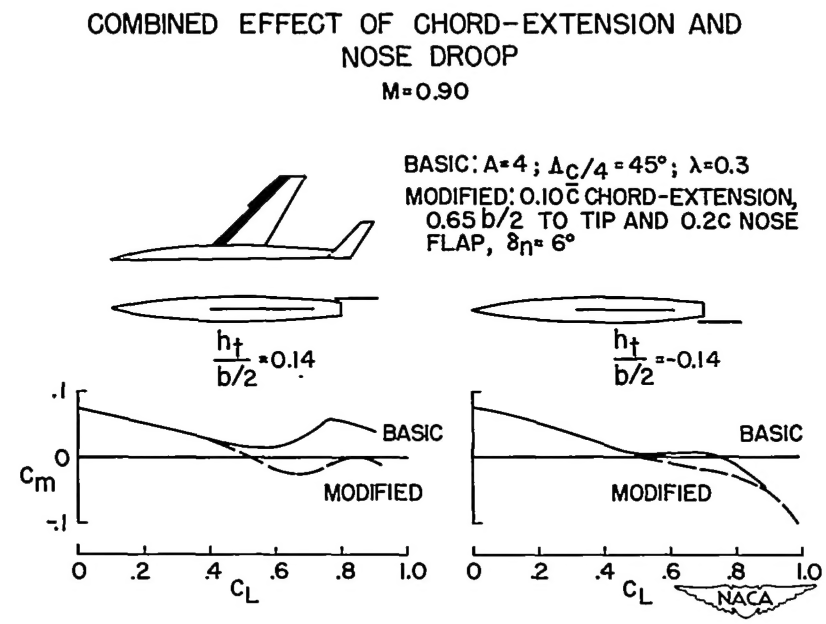

Figure 11

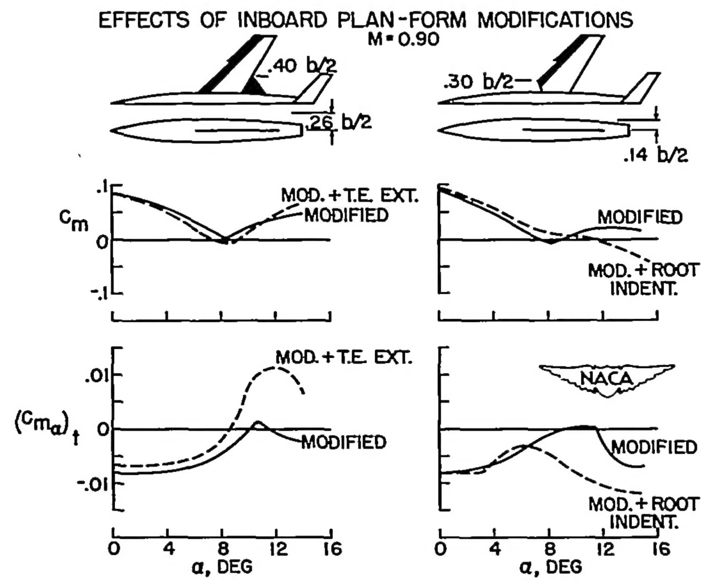

Figure 12

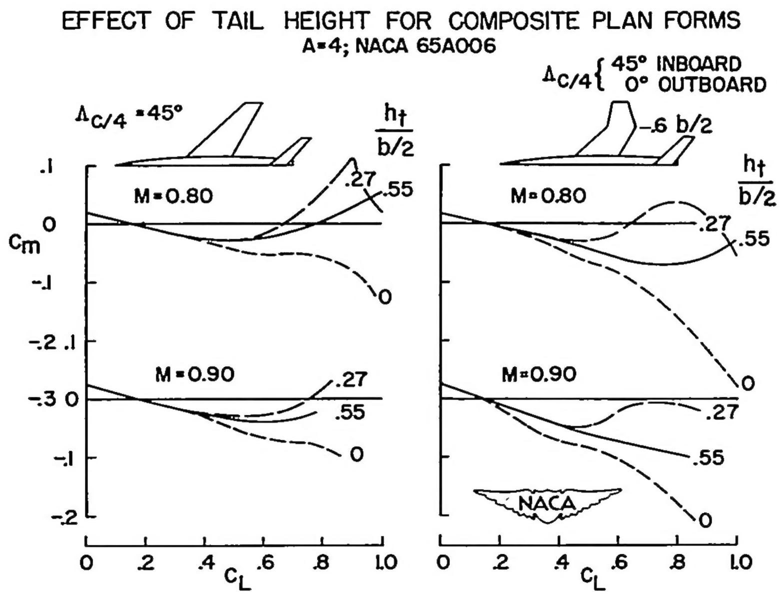

Figure 13

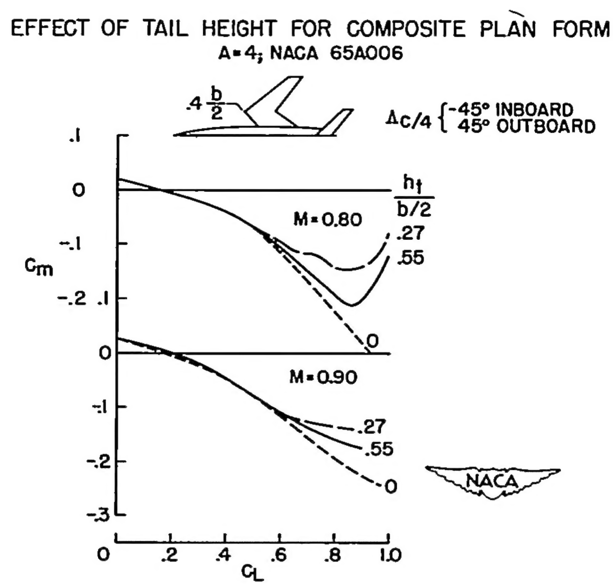

Figure 14

HIGH-SPEED WING-FUSELAGE STABILITY BOUNDARY

M≈0.80 TO 0.95; t/c=0.03 TO 0.06; λ=0 TO 0.7

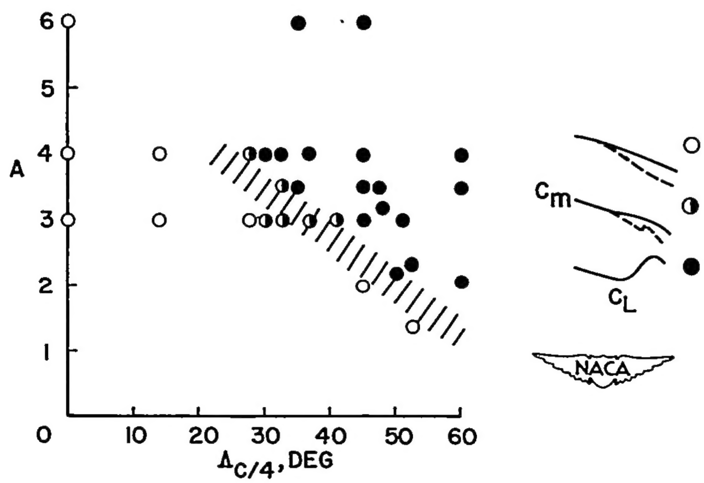

Figure 15